Modeling Quark Compositeness at the Compact Muon Solenoid

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Fermilab

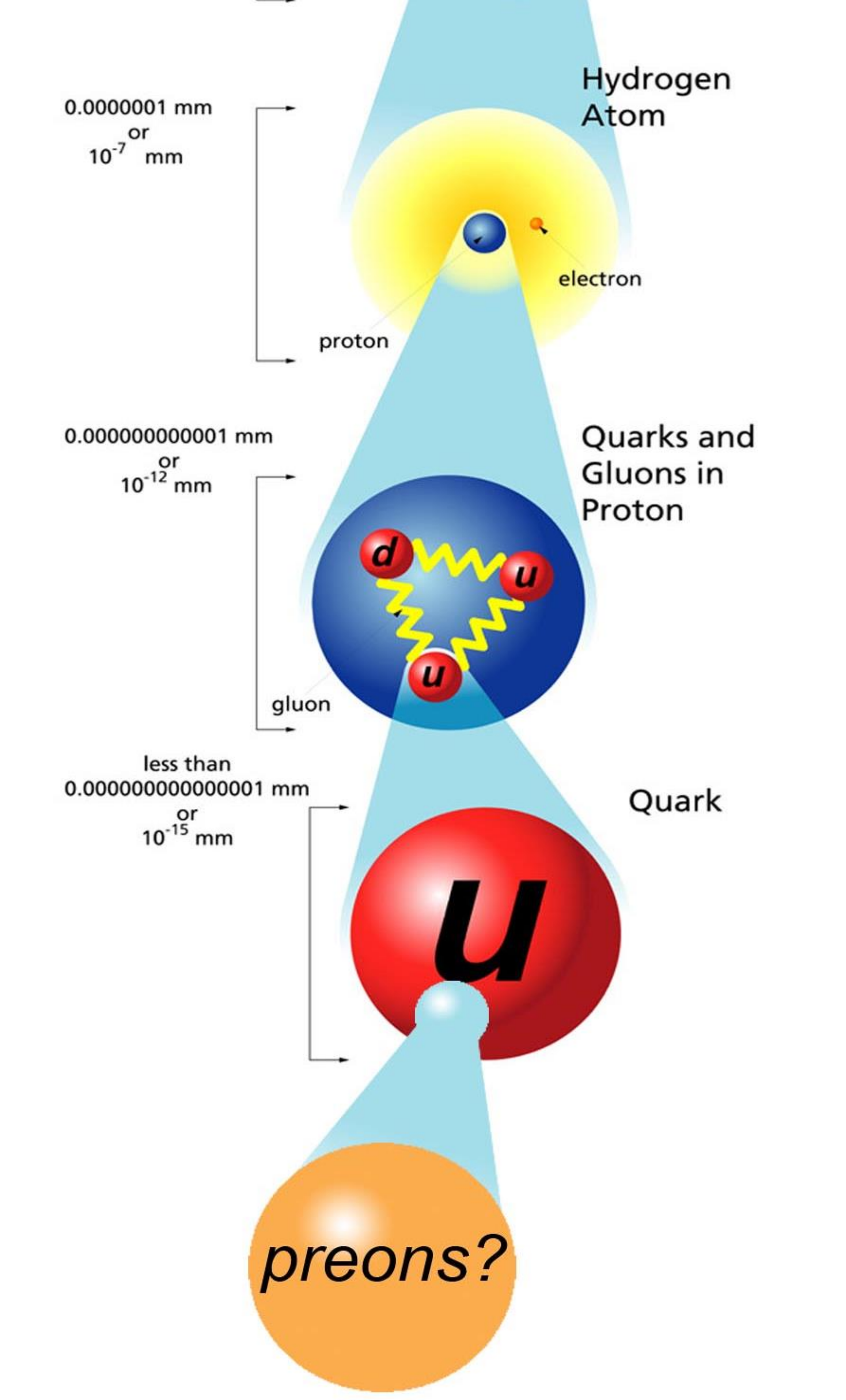
CMS
Compact Muon Solenoid

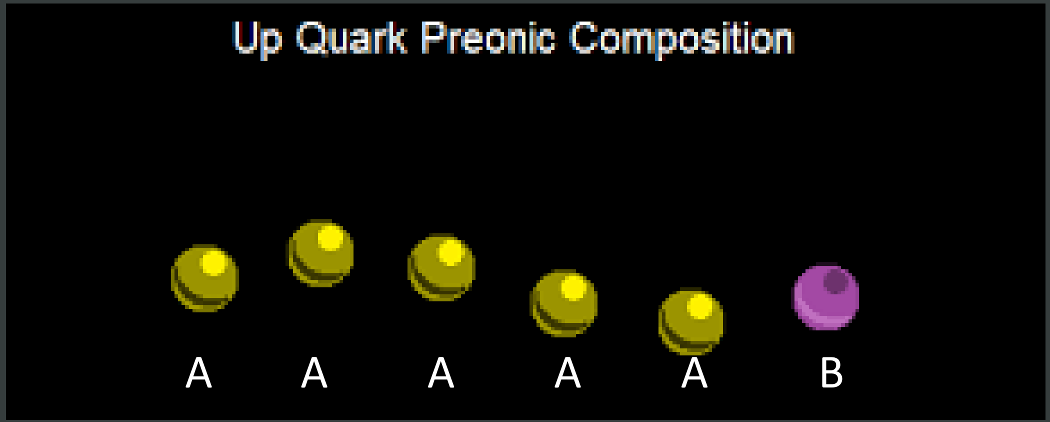
Outline

- Introduction:
  - What is compositeness? How do we find it?
  - How much energy does it take to see compositeness?
- Methods:
  - Invariant mass spectra
  - Collins-Soper Angle
  - Figuring out the minimum energy it must take to see compositeness
- Concluding remarks and acknowledgments

Introduction

WHAT IS COMPOSITENESS AND HOW DO WE FIND IT?



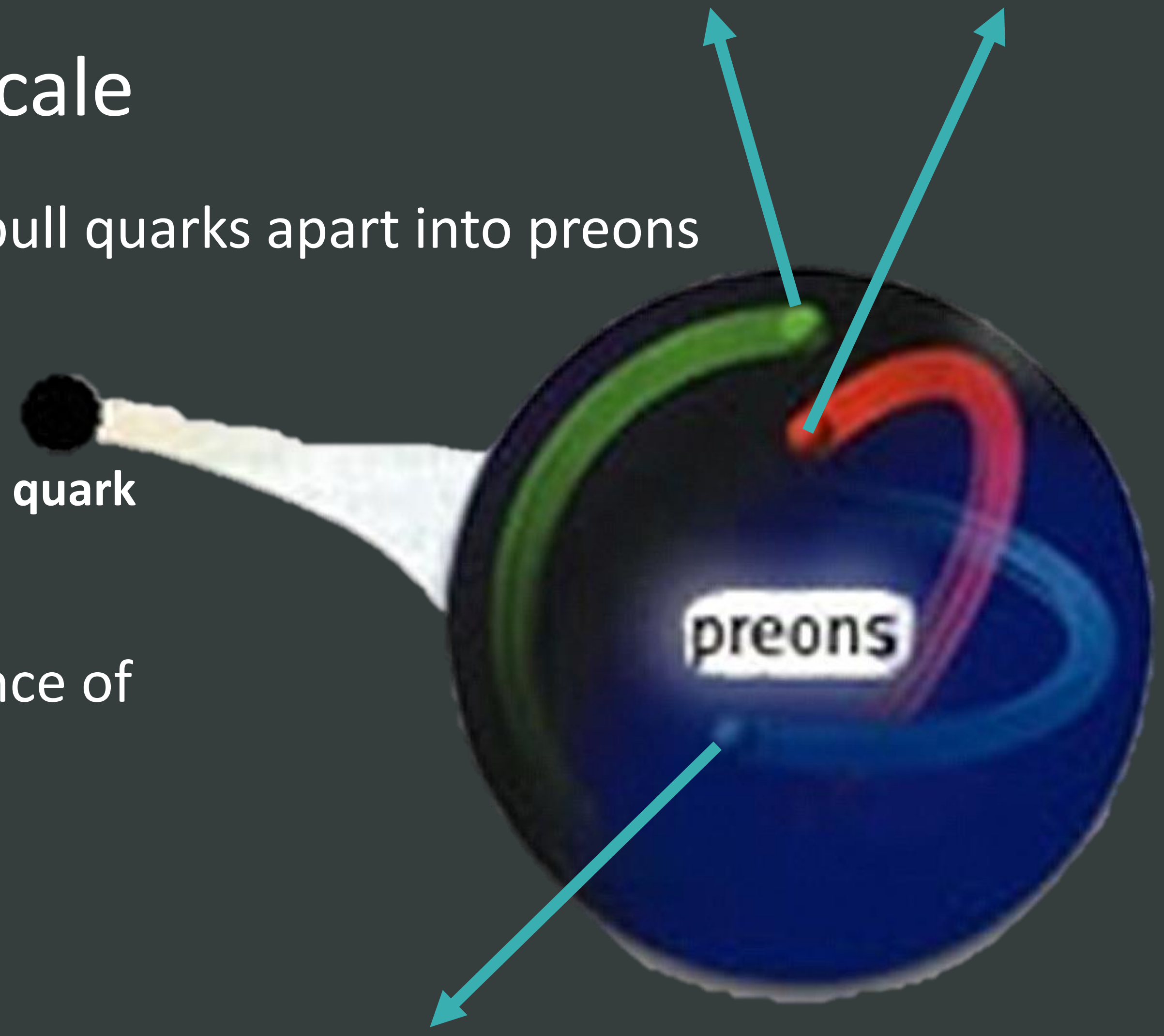


Compositeness is the idea that quarks and leptons are made up of even smaller particles

These smaller particles are called *preons*.

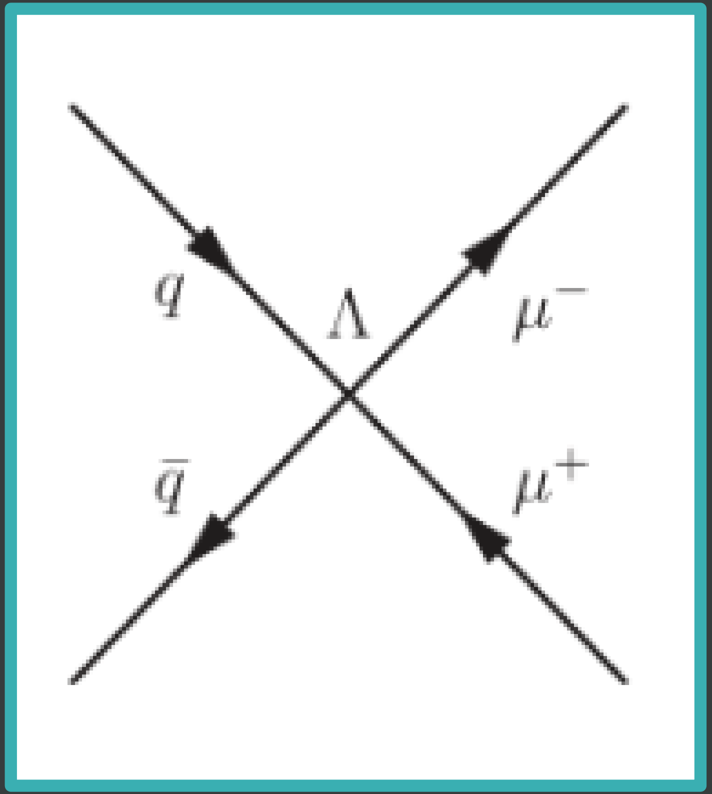
Λ : Compositeness Energy Scale

- Similar to the energy that it takes to pull quarks apart into preons



- Energy at which we can detect evidence of compositeness

What Compositeness Predicts

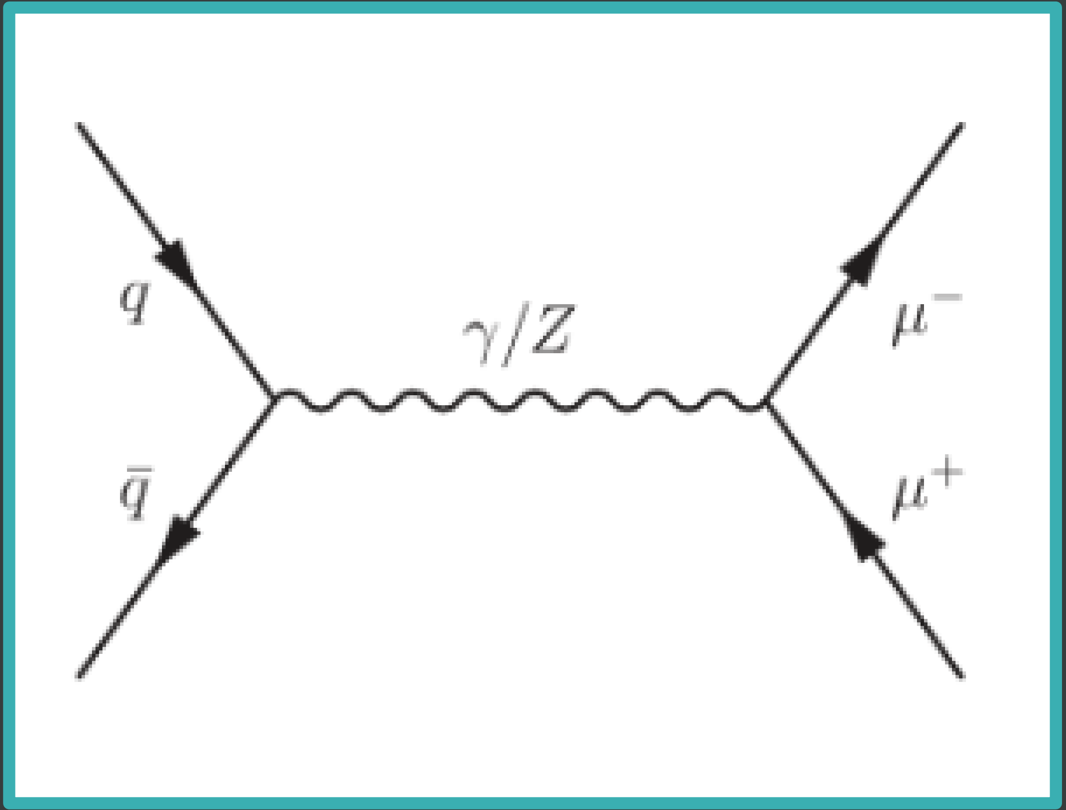


time

- Contact Interactions (CI)
  - Instead of transferring a particle, preons make direct contact with each other
  - Quark and antiquark each give a preon, which interact to give a muon and antimuon
  - If CMS finds CI, this shows that compositeness exists

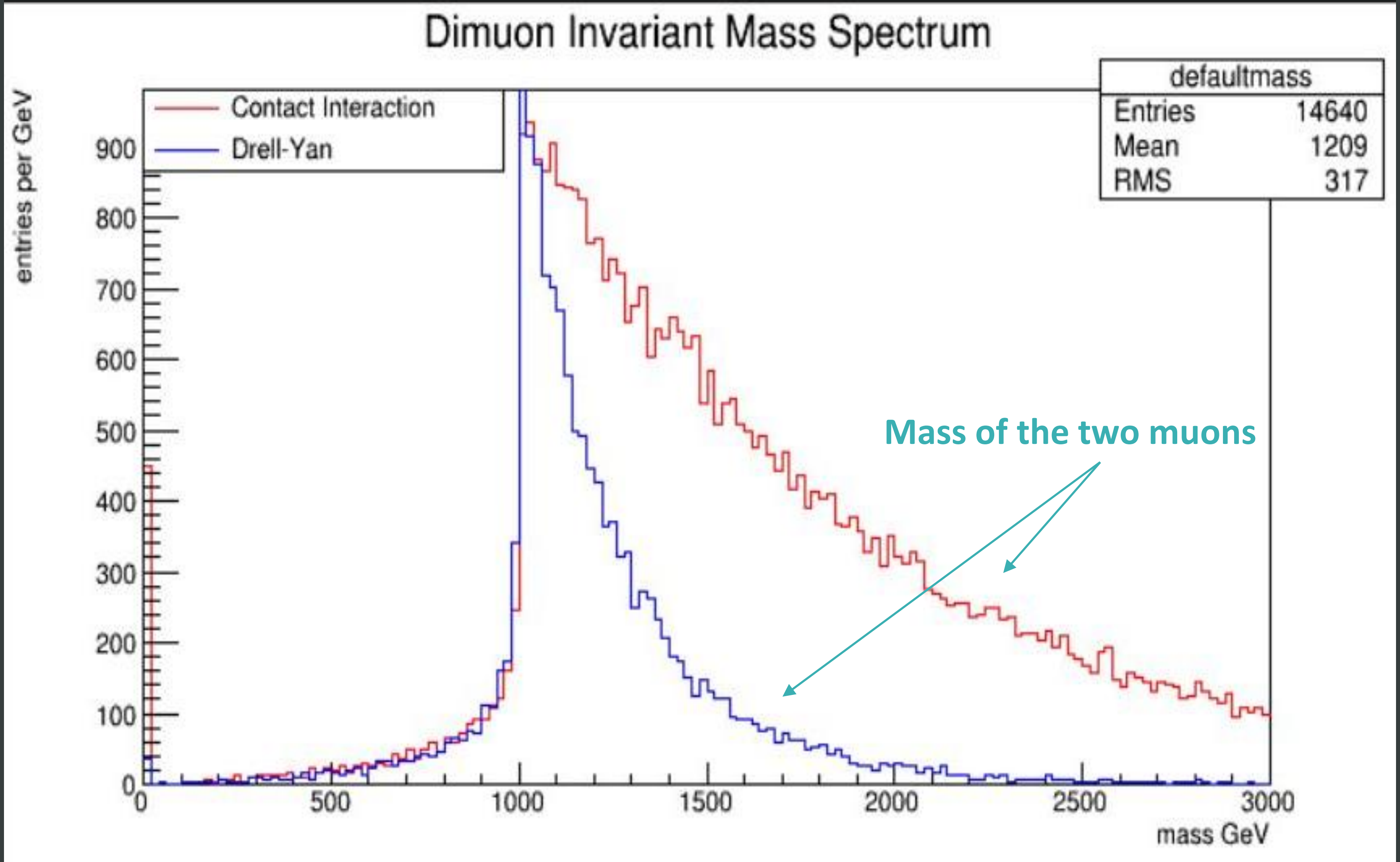
Background: Drell-Yan

- Drell-Yan (DY) process is the main background
- Also has $q\bar{q} \rightarrow \mu\bar{\mu}$
- Cant see Z/γ*
  - Find other methods to differentiate



Methods

HOW DO WE USE COMPUTER SIMULATIONS TO LEARN ABOUT CONTACT INTERACTIONS?



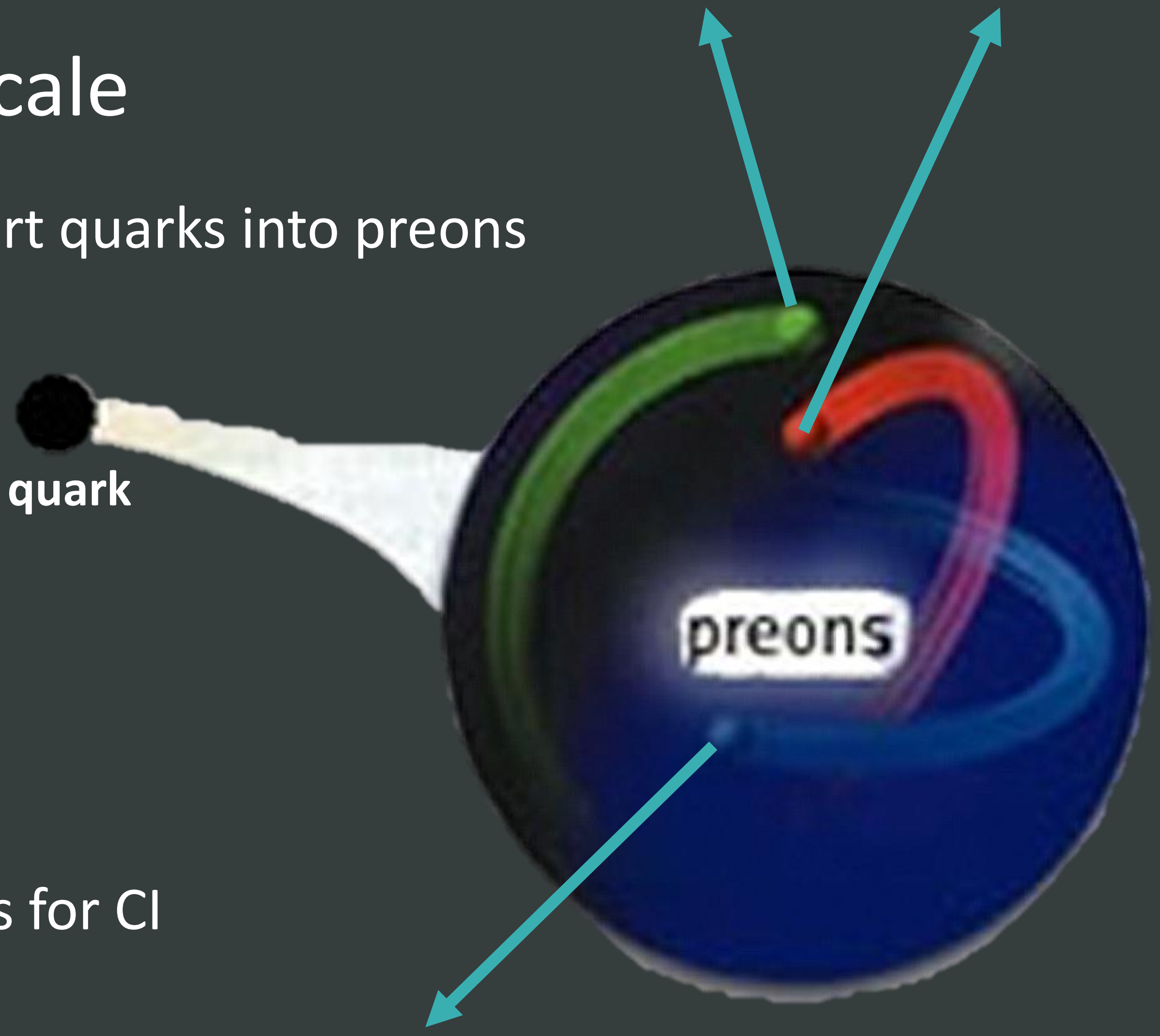
Invariant Mass Spectra

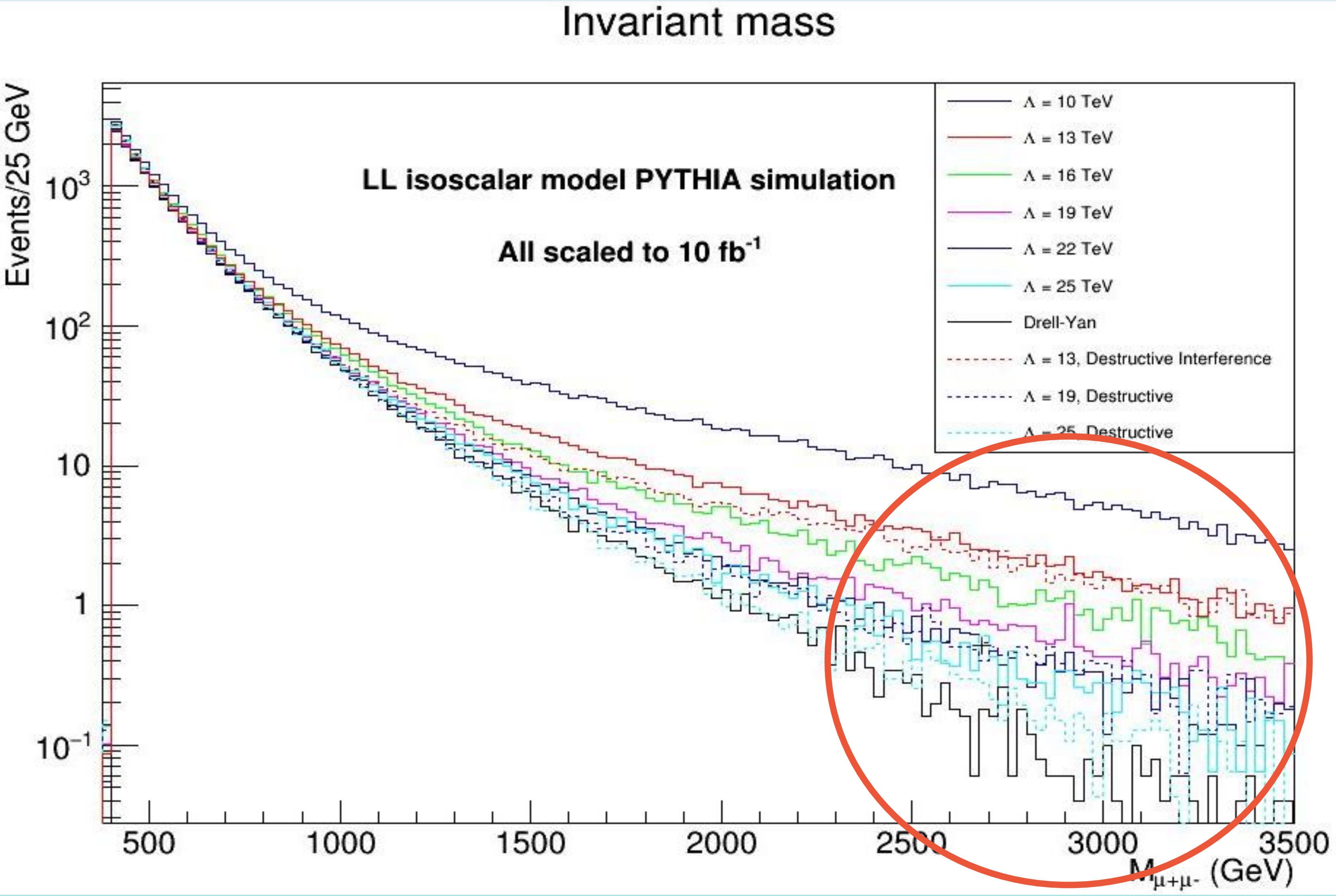
CI makes more high mass events than DY

Invariant mass is related to energy

Λ : Compositeness Energy Scale

- Similar to the energy that it takes to pull apart quarks into preons
- Energy at which contact interactions occur
- Unknown
- Different values of Λ predict different signals for CI

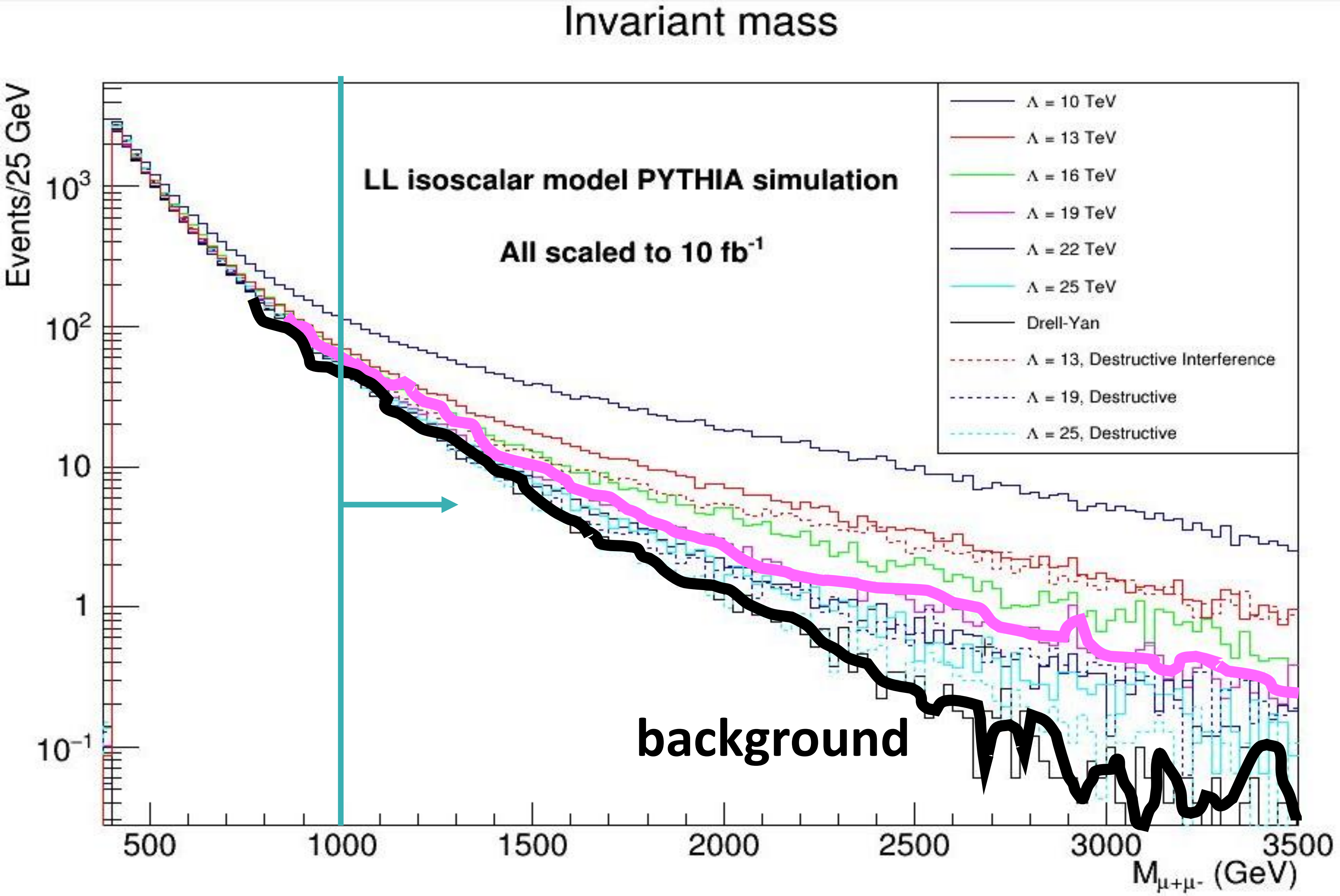




Invariant Mass Spectra

If Λ is high, there are fewer high mass events and the invariant mass spectrum for contact interactions is hard to distinguish from that of the Drell-Yan process.

Need to look at high mass events to see the difference

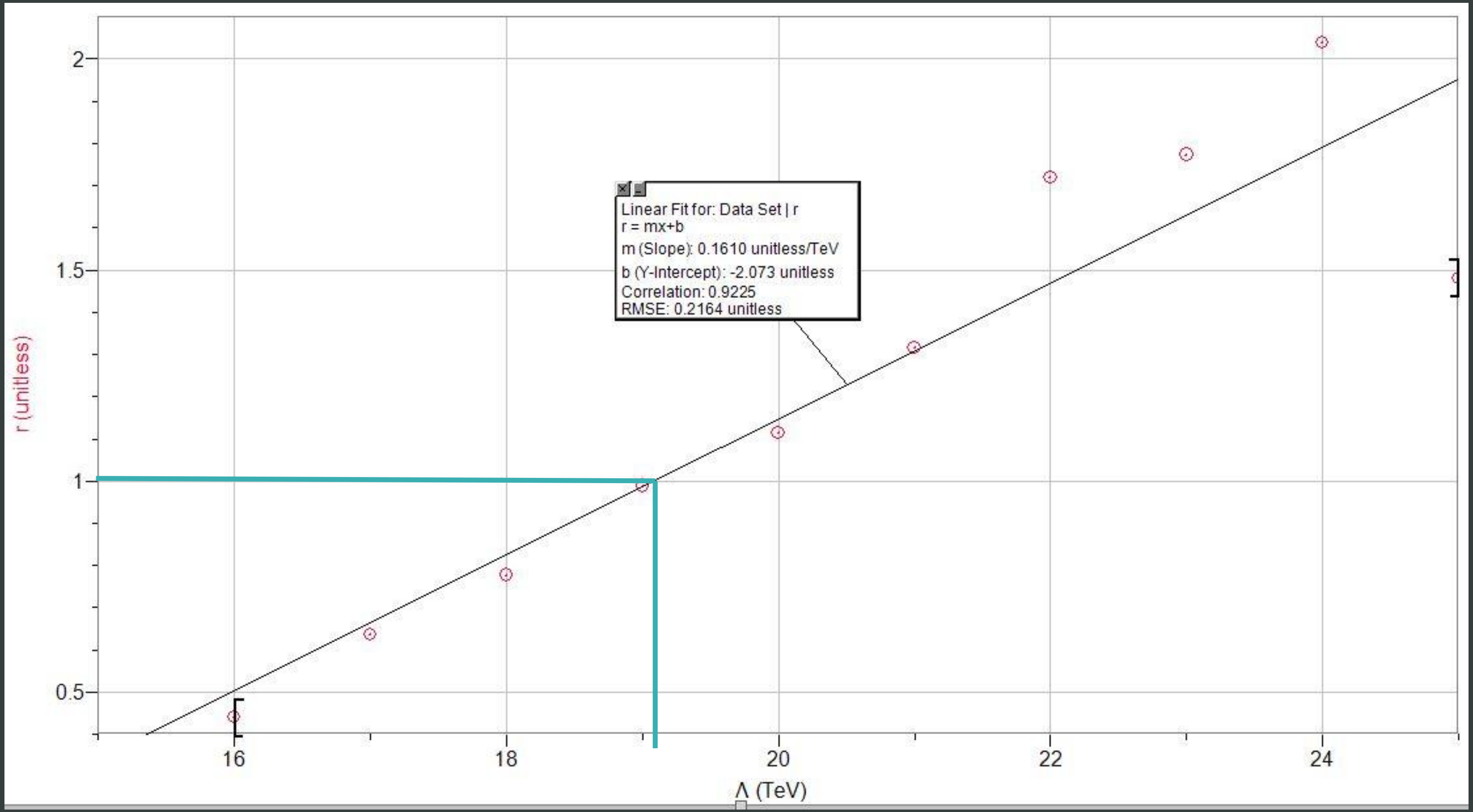

Invariant mass
Events/25 GeV
LL isoscalar model PYTHIA simulation
All scaled to 10 fb^{-1}
Λ = 10 TeV
Λ = 13 TeV
Λ = 16 TeV
Λ = 19 TeV
Λ = 22 TeV
Λ = 25 TeV
Drell-Yan
Λ = 13, Destructive Interference
Λ = 19, Destructive
Λ = 25, Destructive
background
$M_{\mu+\mu-}$ (GeV)
500
1000
1500
2000
2500
3000
3500
10^3
10^2
10
1
10^{-1}

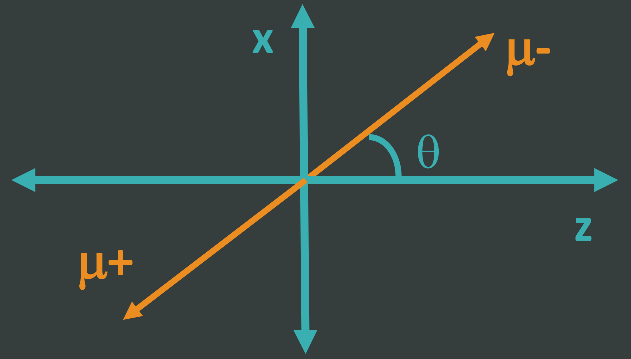
signal

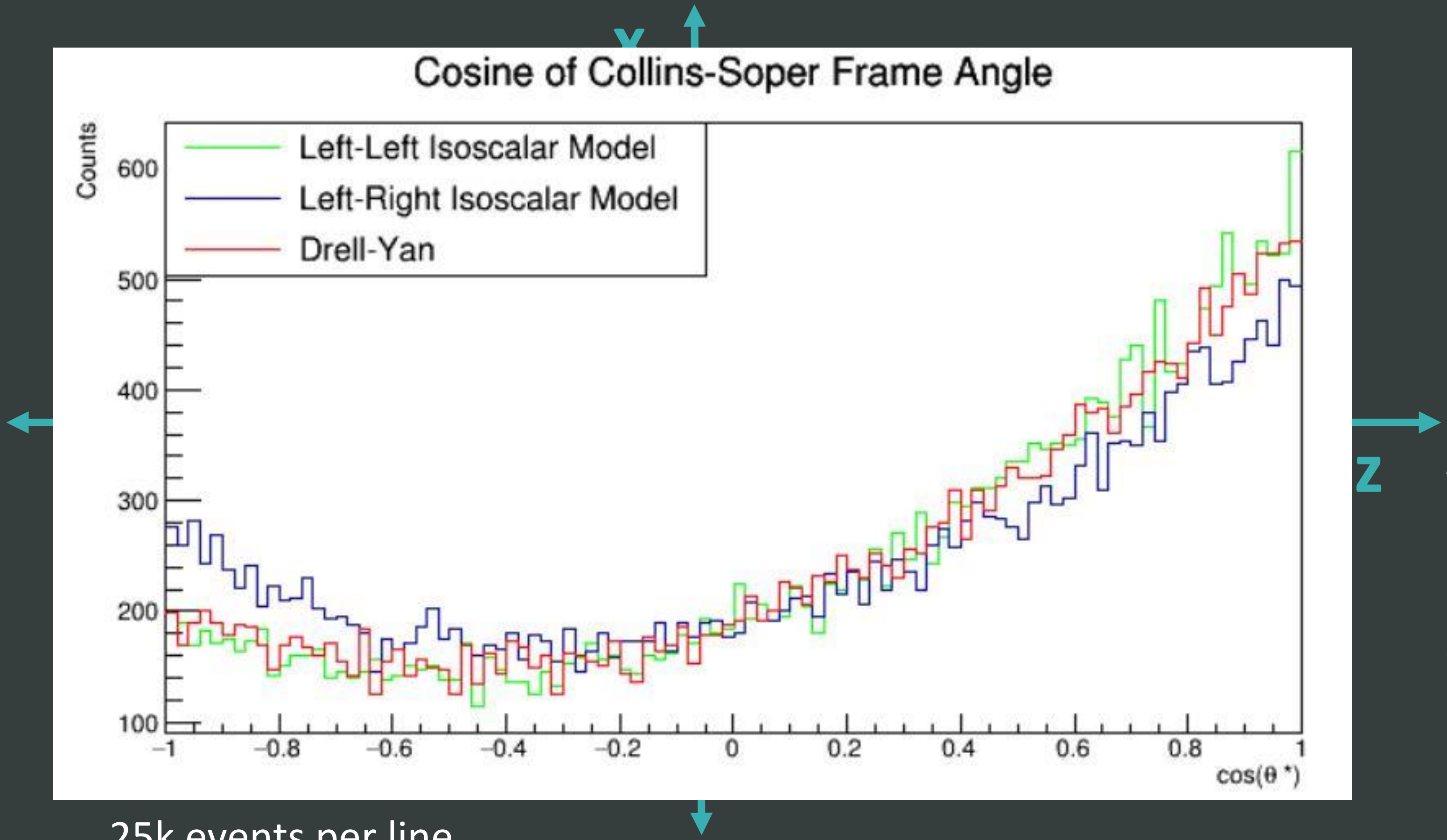
Limiting Λ

Λ = 19.01 TeV

r vs. Λ







25k events per line
Λ = 14 TeV
Minimum mass cut of 400 GeV

Collins-Soper Frame Angle θ

Not symmetric around zero (more positive events than negative ones)

LL and DY look similar, but LR looks different

This difference is more exaggerated at higher mass events

Forward-Backward Asymmetry

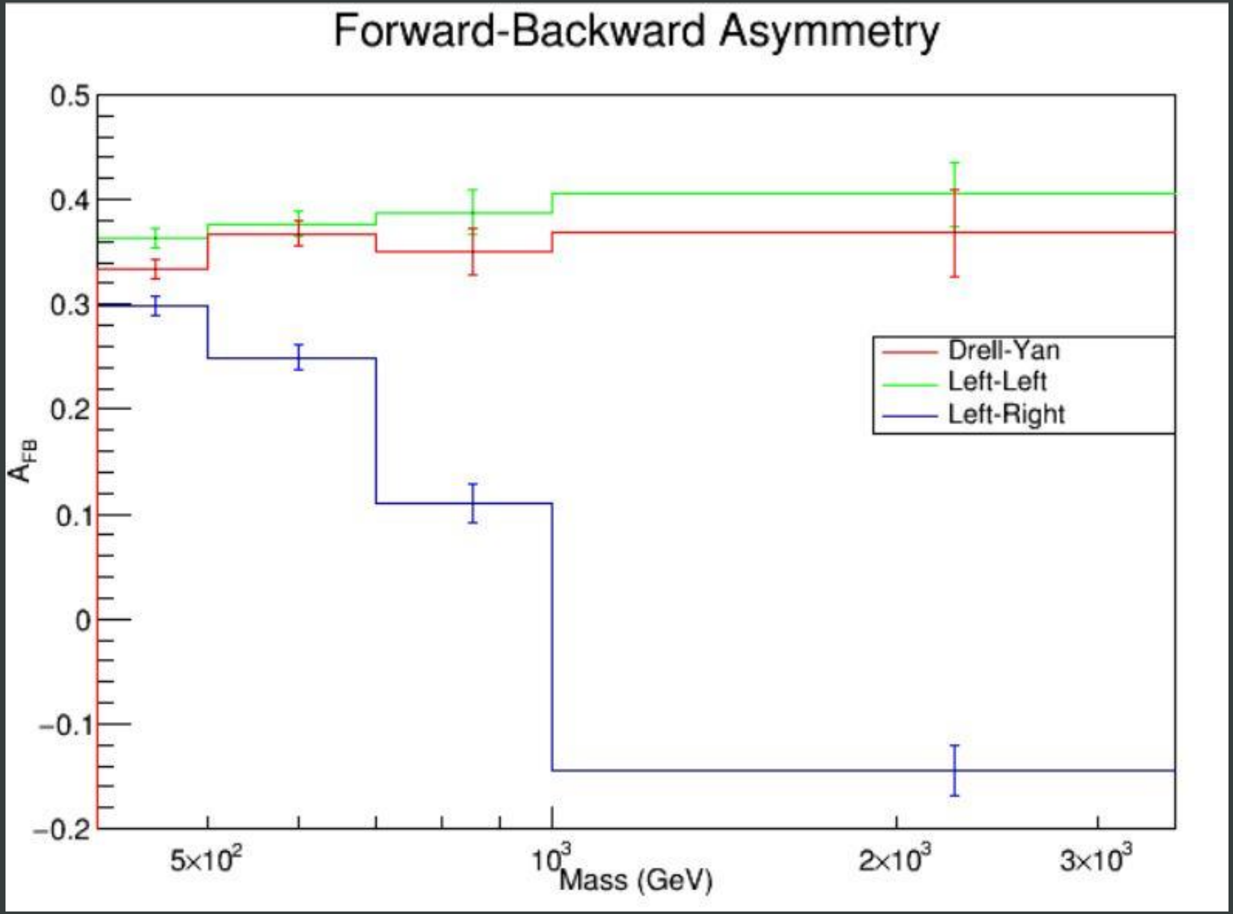
- Measure of cosθ asymmetry around zero

$$A_{FB} = \frac{N_F - N_B}{N_F + N_B}$$

N_F = number of events with cos(θ) > 0

N_B number of events with cos(θ) < 0

- CI (signal) and DY (background) are most differentiable at high mass events, so we plot A_{FB} as a function of mass



Concluding Remarks

Acknowledgements

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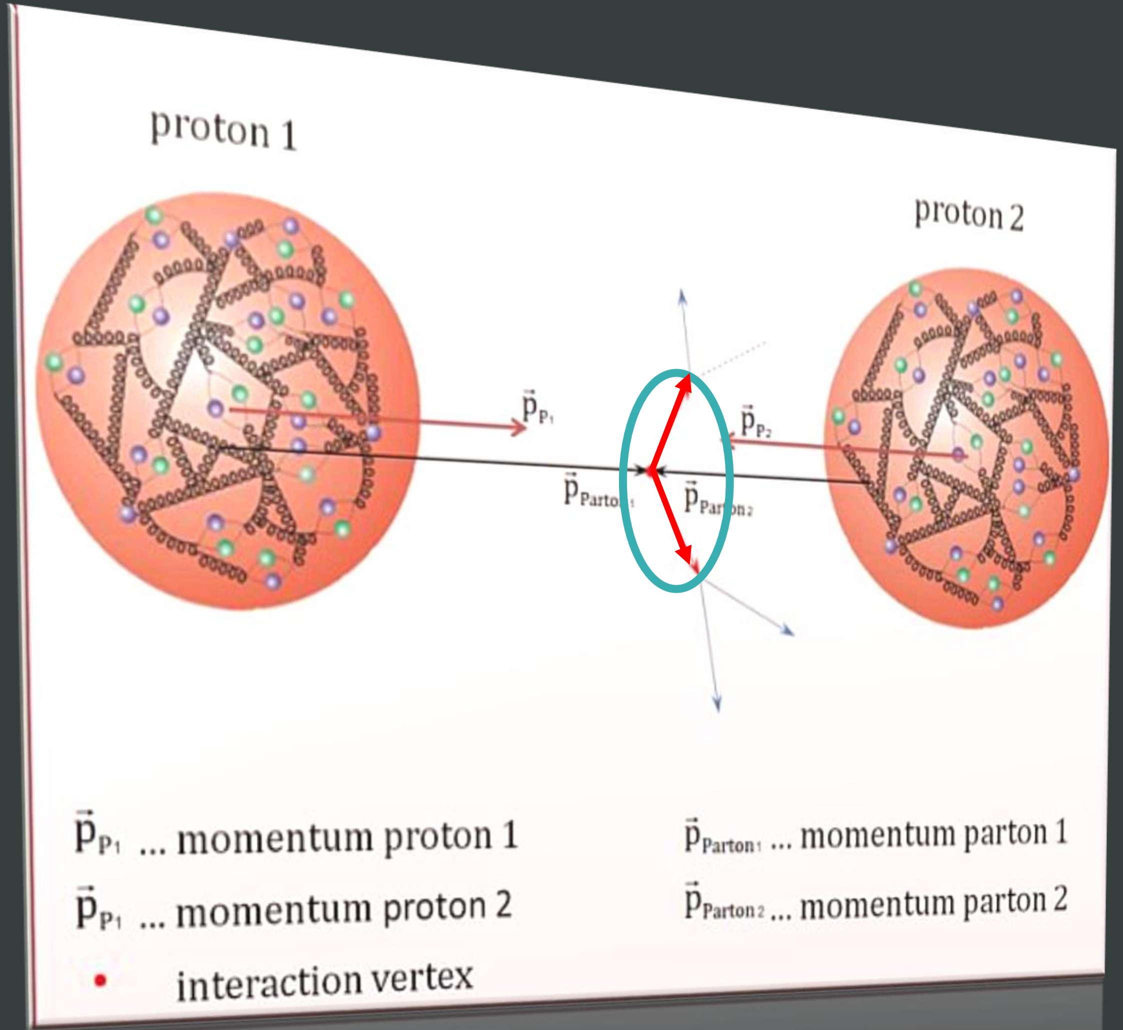
Limiting Λ

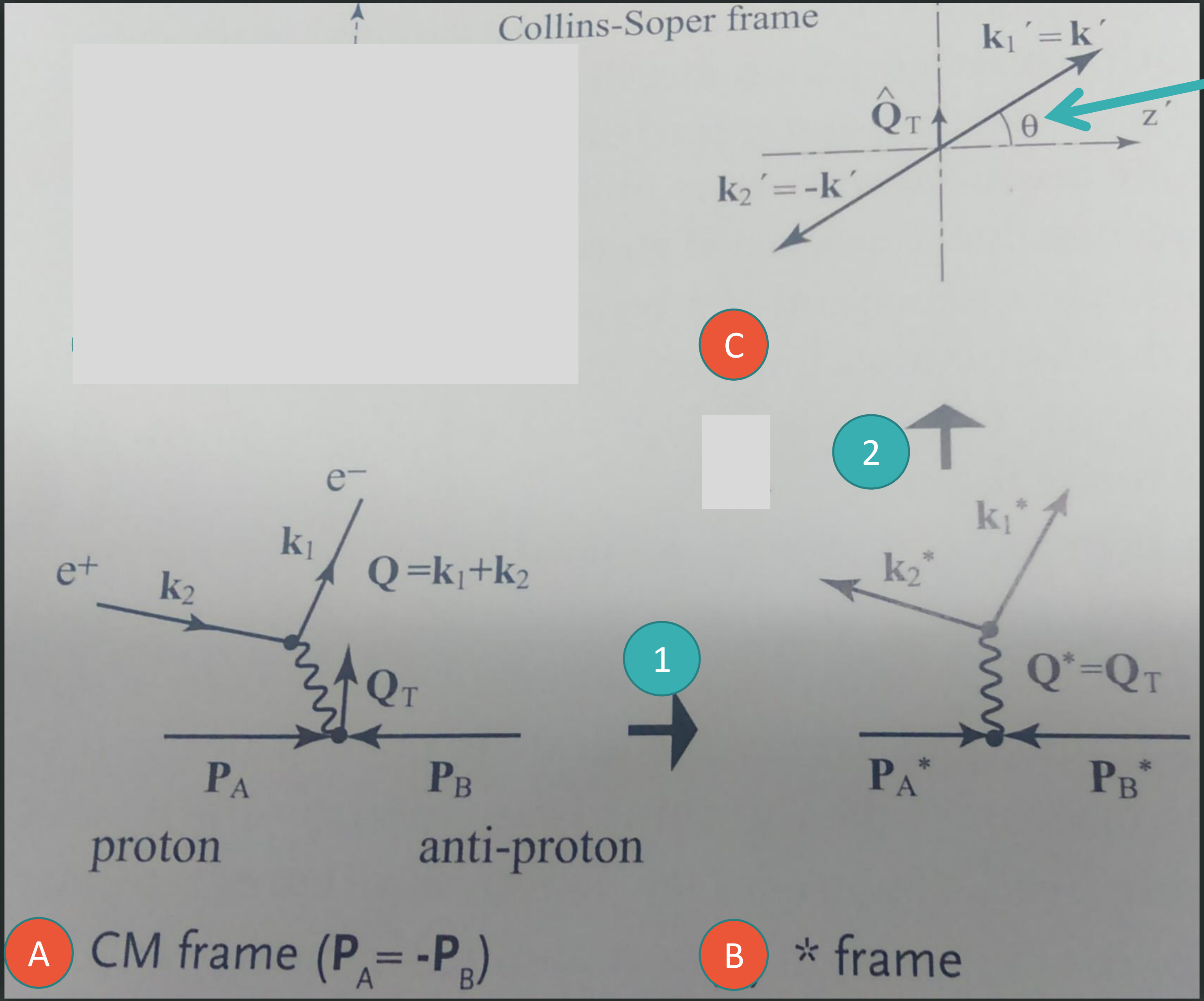
Λ (TeV)	16	17	18	19	20	21	22	23	24	25
CI Yield (events)	92.741	80.183	75.120	70.202	68.155	65.725	62.493	62.181	60.874	64.157
DY Yield (events)	52.095	52.095	52.095	52.095	52.095	52.095	52.095	52.095	52.095	52.095
Difference in Yield (events)	40.645	28.088	23.025	18.106	16.060	13.630	10.397	10.086	8.779	12.062
r = noise/signal (expected)	0.440	0.635	0.777	0.988	1.113	1.316	1.719	1.773	2.039	1.481

Λ = 19.01 TeV

Collins-Soper Frame Angle θ



- Tells us about the "angular distribution" of the muons' momentum
- This distribution is different for different models of compositeness
  - One of these models has a different distribution than the background does
- But what is this angle?



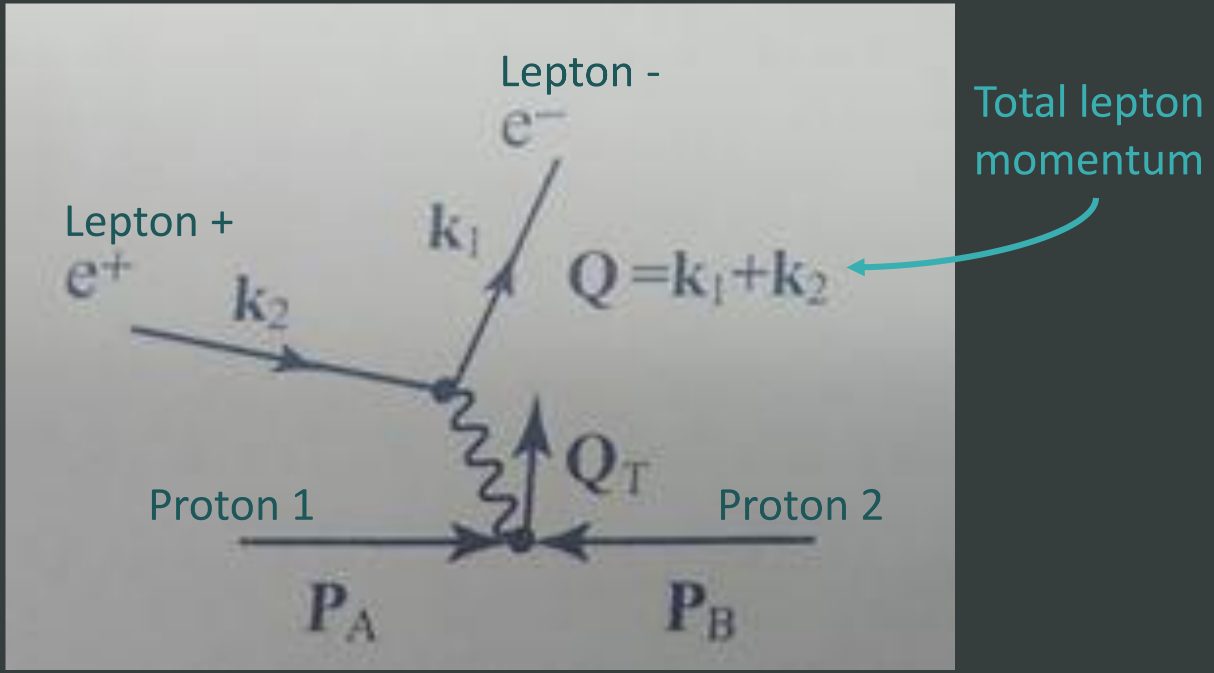
Collins-Soper Frame Angle θ

Two Lorentz boosts:

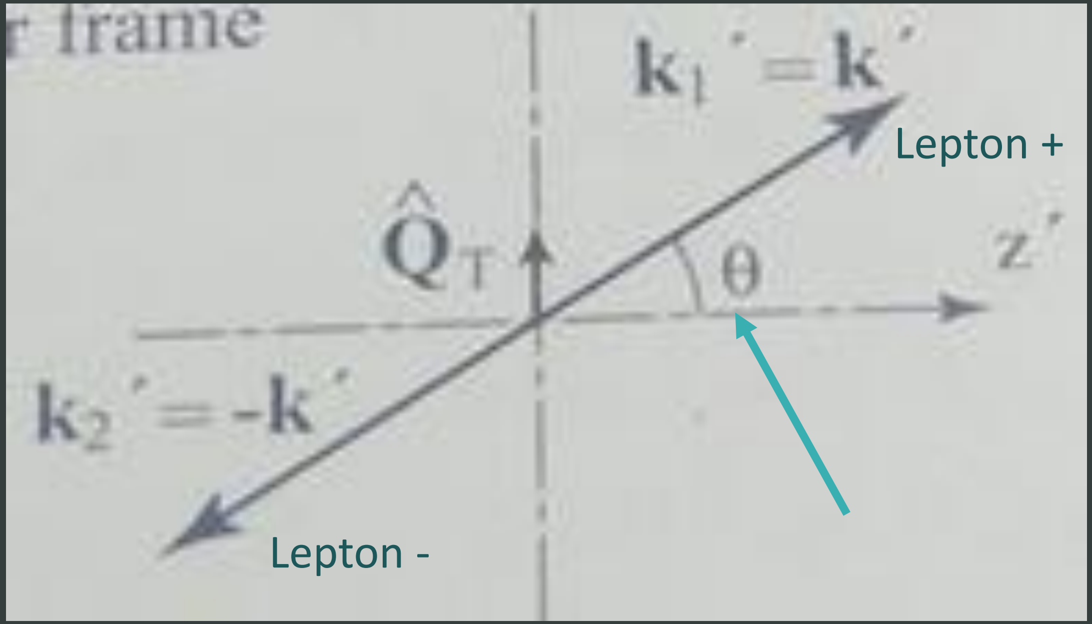
1. Proton center of mass frame to * frame
   - Boost along z-axis
   - Eliminate muon z-momentum
2. * frame to center of mass frame of dimuon system (Collins-Soper frame)
   - Boost along opposite direction of muon transverse momentum (Q_T)
   - Eliminate rest of muon momentum

θ Is the angle that the muons make with the z-axis of the Collins-Soper (CS) frame

Collins-Soper Frame Angle θ



Lab Frame



Collins-Soper Frame

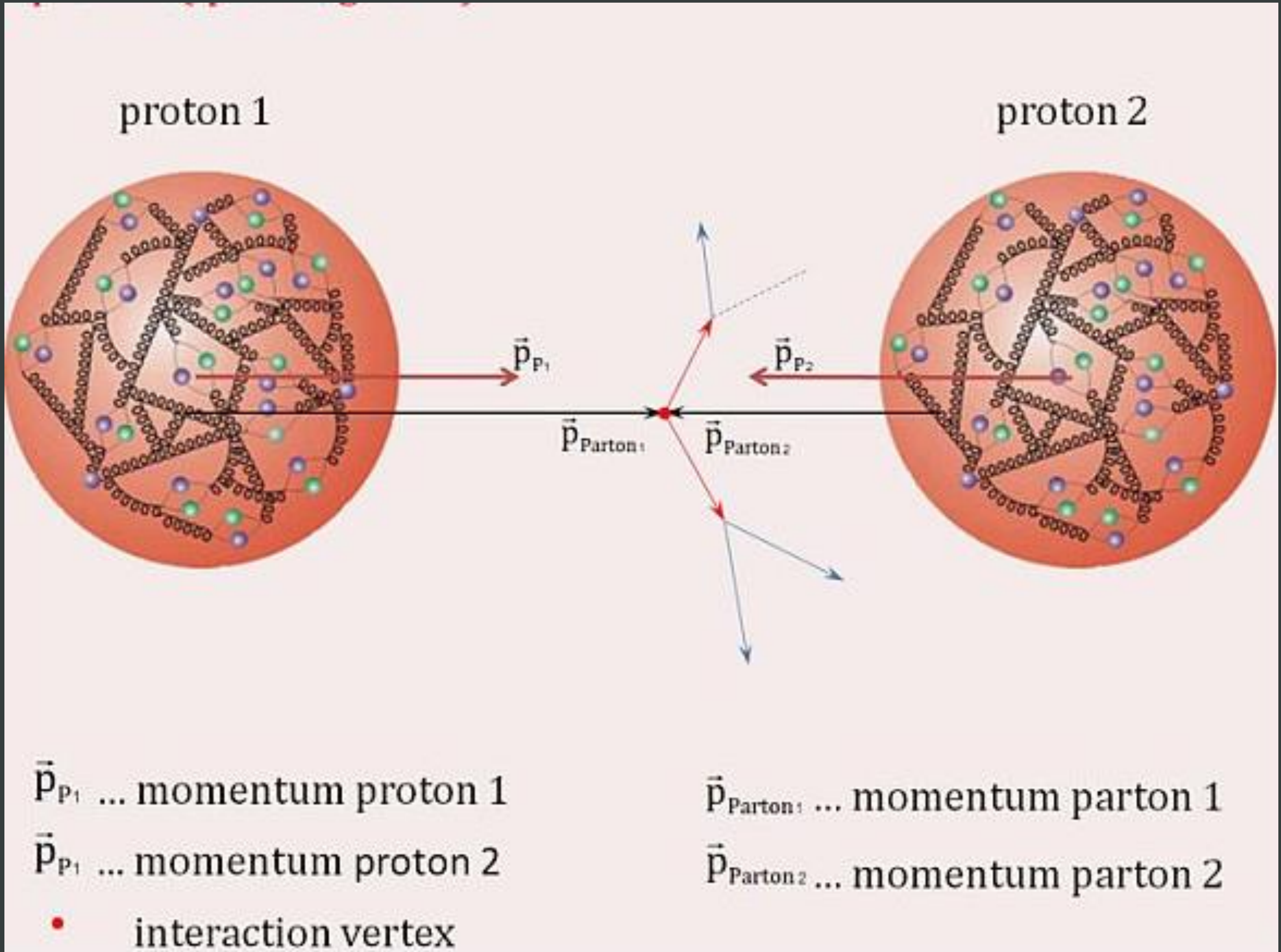
θ Is the angle that the muons make with the z-axis of the Collins-Soper (CS) frame

*Nagashimi, Elementary Particle Physics

Collins-Soper Frame Angle θ

- Want to be able to calculate it in of lab frame variables
  - Things the CMS detector can directly measure from its point of view

$$\cos\theta^* = \frac{p_z(\ell^+\ell^-)}{|p_z(\ell^+\ell^-)|}\frac{2(p_1^+p_2^- - p_1^-p_2^+)}{m(\ell^+\ell^-)\sqrt{m(\ell^+\ell^-)^2 + p_T(\ell^+\ell^-)^2}}$$



Forward-Backward Asymmetry

Sea quarks have less z momentum than valence quarks

Valence quarks: up, down quarks that "make up" structure of proton

Sea quarks: quarks that briefly pop in and out of existence within the proton

Antiquark always comes from sea (no anti valence quarks)

Workflow

PYTHIA

ED Analyzer

Histogram Maker

Importance of Simulation

- In order to properly analyze real data when it is available, need to understand what we would expect to see in every scenario
- This study was entirely simulation based
    - Verify software works before simulate whole detector
    - Develop analysis methods using simulated data and then use them on real data
        - Know what we expect to see, provides objective checks

Goals

SHORT TERM (SUMMER)

- Gain strong understanding of backgrounds
- Strengthen methods to look for signal
- Create and analyze simulation against which to compare real data
- Verify software in order to submit full-detector simulation request
- Develop statistical tools to use for later analysis of real data

LONG TERM (CMS' FUTURE)

- Find evidence for compositeness

OR

- set a strong lower limit on the energy scale at which it will be detectable